# A NEW TYPE OF ERGOGRAPH, WITH A DISCUSSION OF ERGOGRAPHIC EXPERIMENTATION.

By Professor JOHN A. BERGSTRÖM, Indiana University.

Apparatus for the study of muscular strength and endurance may be arranged in a series beginning with that designed like the common myograph or Mosso ergograph for the study of the action of isolated muscles or single muscle groups and ending with that which brings into play many, or as nearly as may be, all the muscles of the body.

Excellent recent examples of the latter type may be found in the physiological laboratory of the Carolinska Institute, Stockholm, and in that of the University of Lund. The apparatus at the Carolinska Institute is made on the plan of a weight rowing machine, and is equipped with elaborate devices for regulating the rate and character of the work, and for registration. Together with the man subject to experiment, it is enclosed in a large air-tight chamber, the gaseous contents of which may, from time to time, be chemically determined. It seems admirably arranged for the study of many of the conditions, and also effects, of muscular work of a complexity and difficulty comparable with that of many forms of ordinary labor. The apparatus, planned by Professor Blix of Lund, resembles a bicycle, the resistance to motion being furnished by friction applied to the axis of what corresponds to the driving wheel. An ingenious recording mechanism gives a continuous curve of the pressure exerted throughout the work. This piece of apparatus is intended especially for the study of the greatest possible muscular effort and seems well adapted for its purpose.

Most forms of hand dynamometers and dynamographs may be said to occupy an intermediate position. One of the simplest and best of recent models can be seen in the laboratory of Dr. Alfred Lehmann, at the University of Copenhagen. It consists essentially of an adjustable spring dynamograph attached to a base, which also carries a transverse ridge, against

which the thumb and back part of the hand are braced in making records. The position of the hand seems firm and convenient.

In the description of the ergograph in *Du Bois-Reymond's Archiv*, 1890, Mosso points out very clearly the advantages, for the analysis of neuro-muscular activity and fatigue, of the isolation of the muscle to be used, and of making the conditions of load and registration as nearly as possible like those in experiments with excised muscles.

This ideal he does not, however, realize in his own work, as he recommends the use of the whole middle finger in experiments, the collar for the attachment of the weight being placed around the second phalanx. Several muscles are involved in the movement, the lumbrical and palmar muscles as well as the flexor sublimis and flexor profundus, which he appears erroneously to have believed to be the only ones concerned. To secure a better isolation of the action of these two muscles, Kraepelin recommended the fixation of the first phalanx and the movement of only the last two; this suggestion appears to have been adopted in most, if not all, of the more recent types of apparatus.

The nearest approach to complete isolation has thus far probably been obtained in experiments with the abductor indicis first recommended for this purpose by Fick[1] and recently adopted by Lombard in a late type of ergograph.

## I.

With the instrument to be described in this paper, it is possible to obtain practically the complete isolation of the flexor profundus in its application to each finger of either hand; also, almost, if not quite, the complete isolation of the abductor indicis and the abductor minimi digiti. In addition experiments may be made in which the flexor sublimis, while not isolated, plays much the leading part. Records may also be obtained from the flexion of the second and third phalanges together, from the extension of the third, or second and third phalanges, and from the flexors and extensors of the thumb. However, experiments

[1] A. Fick: Myographische Versuche am lebenden Menschen. *Pflüger's Arch.*, Vol. XLI, 1887.

with the flexores sublimes are likely to be rare, inasmuch as experiments with the flexors of the third phalanges and the four abductors are relatively free from objection and do not require so much exertion.[1]

A slight difficulty is experienced with the abductor indicis because of its attachment to the metacarpals of the thumb as well as the first finger. At first some subjects appear to need a brace for the thumb, but this makes it easy to displace the hand. A little practice in voluntarily holding the thumb back in a certain position seems to me to remove the trouble sufficiently.

An important source of error in securing proper isolation, and particularly in maintaining the same position and condition of the moving parts of the hand, has been the fact that all types ot ergographs, as far as known to me, have been placed upon rigid supports and usually clamped solidly to them. Movements of the entire arm, and even of the body, can thus be brought to bear to displace the hand, and, perhaps, to some extent, at times, to assist in raising the weight or extending the spring. With heavy loads or in nearing exhaustion in endurance tests, concomitant movements of nearly all parts of the body are to be observed.[2] With careful training they may in large part be suppressed, and they are doubtless much the most troublesome in beginners. This difficulty, I believe, is nearly, if not wholly, obviated by suspending the ergograph by a spring or by a cord with a counterpoise, so that it may move freely with the arm as it is pulled about in the struggle to make a maximum record. The instrument should be as light as possible to avoid the effects of inertia, and should, of course, be attached to the arm at essential points only. The

[1]This instrument in a somewhat less complete form was exhibited at the Baltimore meeting of the American Psychological Association in 1900. *Psych. Rev.*, Vol. VIII, p. 168. It has been developed largely in connection with certain ergographic studies that have been in progress in the psychological laboratory for several years, and I have received assistance in many ways not only from those whose records appear in this article but from others who have co-operated in these studies, among whom I wish especially to mention Jas. W. Westfall, Clark Wissler, H. H. Niekamp, and James P. Porter.

[2]Clark Wissler: Diffusion of the Motor Impulse, *Psych. Rev.*, VII, 1900, 29-38.

one to be described is attached only to the hand, or in some cases to the hand and forearm, and swings freely from a spring. The fact that the arm and body movements meet only a slight resistance, and produce no alterations in the working parts, appears by itself to check their extent.

A more serious source of error with the present instrument than the above is the pressure that may be exerted by the thumb and fingers against the binding; the movements that may be made at the wrist are also troublesome. However, with care in both binding and clamping, it is possible to make these sources of error combined of so little effect that the center of rotation of the phalanx used will usually coincide quite exactly with the center gauge at the end of a fatigue record.

## II.

The relative effect of the different muscles in producing movement and pressure by the fingers has been a matter of doubt and dispute. The opinion that the flexors of the second and third phalanges were also chiefly concerned in the flexion of the first would appear to have been general till the report of the observations of Duchenne, in 1885.[1] According to him the first phalanx may still be bent vigorously when the flexors of the second and third phalanges are paralyzed through disease, thus showing that the flexor sublimis and flexor profundus are not alone or chiefly concerned in the flexion of the first phalanx. Moreover, he observed that with paralysis of the extensor communis, it was possible for patients still to extend the last two phalanges. The inference is therefore made that the lumbrical and interosseus muscles in the hand are the ones chiefly operative in the flexion of the first and the extension of the last two phalanges.

An experiment like the following, while not complete, can aid in some respects, in a rough analysis. A collar with a depression to allow free play to the tendons is placed around the first phalanx, and then attached to a dynamograph; the second and third phalanges remain free. It is found that some pressure may be exerted while the last two phalanges

[1] R. Müller: Ueber Mosso's Ergographen. *Wundt's Phil. Studien*, 1901, XVII, 1-29.

remain comparatively limp, with a stronger pressure the second becomes rigid, then the third; but even with the maximum pressure it is possible for the subject to move the last two phalanges forward and backward, with respect to the first phalanx, without causing a variation in the total pressure of more than one sixth. If the last two phalanges were themselves pressing against a spring, such a movement might be due to variations in the pressure exerted against it, but this is not the case. If the flexor sublimis and profundus and the extensor communis were the only muscles concerned, these movements could not take place without reducing almost completely the total pressure at each extension of the last two phalanges, providing the flexor and extensor tendons are approximately the same distance from the center of rotation of the first phalanx. These movements could take place either if the effect of the flexors of the last two phalanges upon the first phalanx were slight, so that counteracting their force would produce only a small change, or if the tendon of the extensor concerned were much nearer the center of rotation or actually a flexor of the first phalanx. Both of these conditions are possible in this case. On account of the shortening of the flexor profundus and flexor sublimis, through the bending of the phalanges, their tension is not over a half of the maximum, and the lumbrical and palmar muscles can serve the double function of flexors of the first, and extensors of the last two phalanges.

Figure 1 gives a single record of such an experiment; the curve at the left is proportional to the total pressure of the first phalanx with the aid of all the flexors, under the conditions given; the curve at the right exhibits a similar record, but in this the flexion of the first was accompanied by simultaneous forward and backward movements of the last two phalanges. These show themselves as small variations at the bottom.

A similar but smaller record is obtained if the collar is placed about the second phalanx, and the forward and backward movements are made by the third phalanx, which is left free. Here the only interpretation possible would seem to be that under these conditions the flexor profundus contributes only a little to the force of flexion of the second phalanx.

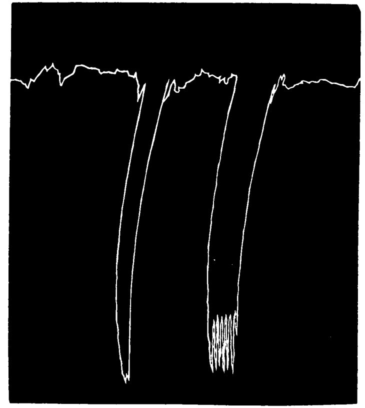


FIGURE 1. (W. A. C.)

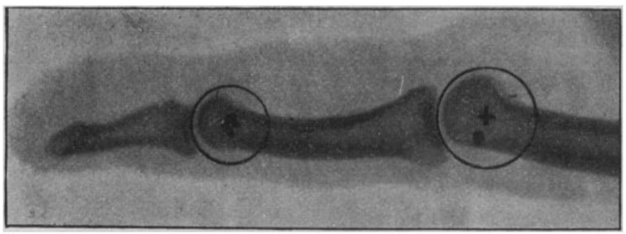


FIGURE 2.

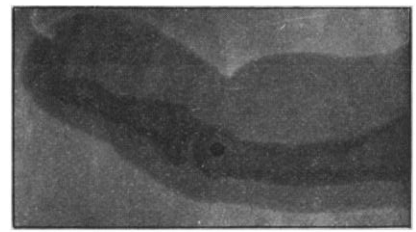


FIGURE 3.

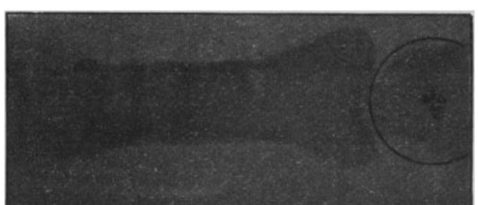


FIGURE 4.

FIGURE 5.

This matter will be made more definite by further experiments.

By a similar method we may attempt to ascertain to what extent the tendon and division of the flexor profundus for a given finger can act independently of the rest.

If an oval dynamometer be held in the hand so that pressure may be exerted upon it only through the last phalanges, we can obtain an indication of the maximum pressure from all simultaneously and from each separately. In a few experiments with two subjects, the sum of the separate pressures from the phalanges approximately equals the simultaneous pressure of all, being in one case somewhat less, in the other somewhat more. This suggests that only a certain definite division of the tendon and muscle are effective in the flexion of any special one of the third phalanges. The same conclusion may also be drawn from the following experiment. If the second phalanx of a given finger be clamped, while the third is free to move but is restrained a little by a small load of about a twentieth of its total lifting power to check slight involuntary movements, it will be found possible, with a little practice, to flex the free phalanges of all the rest of the fingers very nearly as much whether one simultaneously bends the third phalanx of the clamped finger or not; but it is not done with quite the same ease, and the difficulty of flexing other fingers than the one clamped varies somewhat with the different fingers.

However, a possible interpretation of a third experiment would give a contrary view of the matter. If we ascertain what maximum pressure can be exerted by the third phalanx of the clamped finger (1) when the hand is left free, (2) when the first and second, and third phalanges of the other fingers are tied down, we find that the pressure is about the same when the first phalanges are fixed as when the hand is free, but that binding the second phalanges reduces the pressure by about a fifth, and binding the third reduces it to about two-fifths.

Were it not for the two previous experiments, the simplest explanation would be that the parts of the flexor profundus and tendons adjacent to the working division were prevented from rendering the usual assistance by stretching and fixation. It

may be due partly to this, and partly to an interference with the voluntary control by the unusual conditions, and the reduction in the force might be modified by practice. Whatever it may be due to, the fact should be taken into account in binding the hand and fingers in ergographic experimentation.

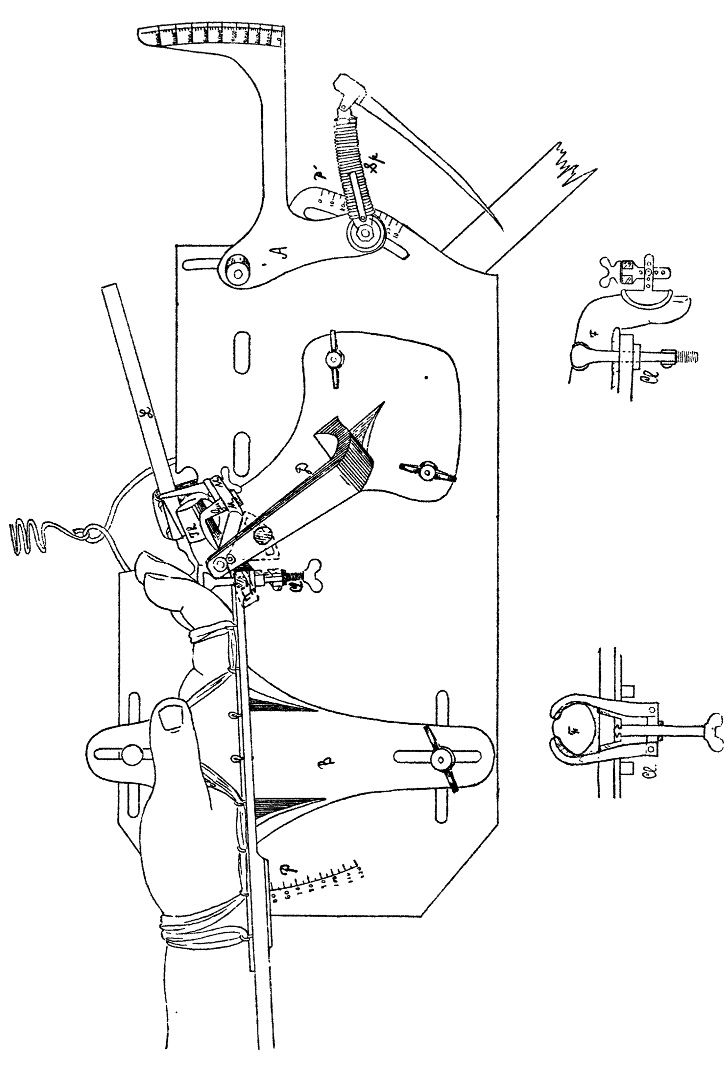
## III.

In the mode of ergographic experimentation to be described, the idea in the fixation of the fingers is to find the essential center of rotation of the phalanx to be used and make it coincide with the center of rotation of the lever against which the work is done. In this case, if the phalanx is rigid, the exact place of application of the load is a matter of indifference, as the load and force of the muscle will vary in case of a change of place in exactly the same proportion, and the load will always remain perpendicular to the moving parts.

The center of rotation is found by reference to the folds of the skin and by observing the phalanx as it moves. The relations of the parts and the location of the centers of rotation will be seen in the x-ray photographs given above in Figures 2, 3, 4, and 5. The centers of the crosses are the true centers of rotation. Small pieces of lead were placed upon the spots usually selected as centers of rotation in experiments and appear as round dots. They were liable to some displacement from projection, but in three out of the five cases the crosses and dots come fairly close together. The circles were drawn to indicate approximately the circumference of the surfaces of rotation.

Figure 2 represents the bones and joints of the middle finger of the right hand; Figure 3 shows the third phalanx partly flexed; Figures 4 and 5 show the first phalanx of the first finger before and after abduction, respectively.

The manner in which the hand is placed in the apparatus for experiments with the flexors and extensors is exhibited in Figure 6. The bracket B is adjustable so that the center of rotation of the phalanx may be brought into coincidence with the center of rotation of the lever of the apparatus as indicated by the center gauge Ga.



6 a. FIGURE 6. 6 b.

In the reproduction of the original drawing of this instrument the letters Ga have become nearly indistinguishable. They lie about the middle of a straight line drawn from the letter D to the tip of the middle finger.

In experiments with the extensors the hand is placed palm down and the adjustment and application of the load is made as shown by 6 b, while Figure 6 itself exhibits the same facts with regard to experiments with the flexors. Experiments with the flexors of the thumbs may be made with the same means, but for experiments with the extensors of the thumb a special bracket, which would permit placing the fingers below, would have to replace B.

A device of special importance is the clamp Cl (Fig. 6 a) for holding the phalanx preceding the one moved. If a circular band is used, it may be made so tight, even within the limits of endurable pain, as to cause a very considerable reduction in the extent of movement and in the maximum pull.

This is probably due to the friction produced on the tendons. If, on the other hand, the band is loose, so as to permit some movement, both the height of lift and the maximum pull will be considerably increased, and we shall have the effects not of an isolated muscle but of the partial co-operation of two or more. In any case the use of the band or plain circle about the phalanx produces variations not easily taken into account. These sources of error may, I believe, be wholly avoided in experiments by careful use of a clamp like Cl (Fig. 6 a). It leaves the space over the tendons free; moreover, the width of this space varies automatically with the size of the finger, and as the jaws are forced down towards the bone they at the same time push the flesh up into a ridge, thus preventing binding. It is adjustable to fingers of any size simply by the movement of the screw. The clamp moves in a slot near the edge of B, and can be set at any point, as can be also the adjustable holder of the thimble, attached to M M.

The phalanx in the clamp must be fixed solidly, if accuracy is to be attained. To make it sufficiently so, it has not been necessary to pass the pain threshold with the subjects I have had, and a great enough variation in the tightness is permissible to make the adjustment of the clamp merely a matter of ordinary care. This applies to all adjustments except that for movements of extension, in which case felt must be put under the jaws, as the pressure becomes speedily painful. One may

judge that the clamp is sufficiently tight either by the fact that the phalanx clearly cannot be moved, or by the fact that any further increase in the pressure does not reduce the heights of the lifts.

To secure accuracy two other matters must receive careful attention. A is an adjustable arrest for the lever L. The angle at which the phalanx begins its movement is determined by the relative position of A and B, which may be made definite by reference to the circular scales P and P′.

If the purpose is simply to secure the same position of the phalanx at different times, it will be sufficient to move A and B to the same readings and center the phalanx by aid of the gauge, Ga. If, however, we wish to make comparative records, and to have the angle the same under these different conditions, the distance of the center of rotation above the top of B must be taken into account in adjusting by scale P. The importance of this angular adjustment will be evident from Figures 7 to 10 below. The maximum pull diminishes regularly to about one-half with a change usually of less than 50° and the angular movement of a muscle loaded with one-half or more of its maximum is nearly to the same point, whatever the place of starting may be. An angle of 180° may be taken as the standard starting point.

This angular error is also the chief one to be considered in the adjustment of thimble, Th. It may be placed nearer or farther from the center of rotation without affecting the record much, but a variation in the tightness with which it is forced on the finger leads to considerable differences because it makes the angle at which the phalanx starts greater or less. In practice the thimble is forced onto the finger till it is even with the end. A corresponding degree of tightness is necessary for comparative records and in any given case the number of the thimble used should be noted. A thimble with a top adjustable by screws might for certain purposes have some advantage, but the plan adopted was to have a set of thimbles at hand from which one of the proper size is selected.

The second of the two precautions referred to above is proper centering. Both the angle of starting and the distance of the load from the center of rotation will vary in ways that will be easily imagined from the geometrical relations of the parts in-

volved. Placing the center of rotation of the phalanx ahead of the center gauge, for example, will give it an advantage at the beginning of flexion but a relative disadvantage at the end, both because the lever of application of power is longer than at the start and because the angle of movement is relatively greater than it would be if the center coincided with the edge of the center gauge.

If an instrument of measurement is to be completely adapted to its purpose, it must give its results in absolute units. For some ergographic problems, however, it would suffice if it were made possible to use a muscle or group of muscles again under exactly the same instrumental conditions, so as to give a series of comparable records with the same member. By attention to the adjustments discussed above this may easily be done with the ergograph here described.

A still higher degree of usefulness would be attained if experiments could be made on different phalanges of the same or different persons under conditions sufficiently similar to make even such records accurately comparable. This, too, is evidently possible, so far, at least, as we may assume that different phalanges and joints are similar.

It remains, therefore, to see how nearly we can refer the records to the elementary geometrical and mechanical properties of the working parts and to ascertain to what extent they may be directly compared with the records obtained from excised muscles in the myograph, with which such reference is possible.

I have not had the opportunity of attempting to solve this problem, as did Mosso, for the whole finger, by a direct comparison between the shortening of the muscle and the angular movement of the phalanx, but the facts may, I believe, be inferred from the appearance of the joints in Figures 2 to 5. The bearings of the phalanges appear to be circular. If the flexor tendon were attached directly at the surface of rotation of its phalanx and moved over the circular surface of the one with which this articulates, the amount of movement of the tendon would clearly be directly proportional to the angular displacement of the phalanx. This will also be true at whatever point the tendon may be attached to the phalanx, as long as it rests upon the circular surface of the preceding one, and it would be

approximately true for a considerable angular distance beyond that at which the tendon would naturally pull away from the surface, if it were kept near it by ligaments. This applies also to the muscle attached to a succeeding phalanx, as, for example, to the flexor profundus in the rotation of the second phalanx. Such a muscle will, of course, not be effective till the phalanx to which it is attached has reached its own limit of motion, unless it be counterbalanced by an extensor which is nearer the center of rotation or is at the same time a flexor of the preceding phalanx.

For our present purpose the important point to examine is, therefore, whether in the bending of the phalanx the point is ever reached where the tendon is lifted from the surface of rotation so as to alter the radius of application of the force. In feeling of the joints in flexion the tendon becomes a little more prominent in the second, but hardly appreciably so in the third. From a consideration of the relative position of the phalanges in the x-ray picture, it does not seem probable that with the usual degree of flexion in ergographic experiments, the tendon will change radius with respect to the rotation of the phalanx to which it is attached. That there will be a tendency to such a change in the relation of the flexor profundus to the second phalanx seems probable. This may explain the peculiarity of Figure 9 and the difference between this and Figure 10 below. The fairly regular gradations of heights in all figures except 9 is another evidence that there has been no change in the mode of applications of the force.

These conclusions may be generally valid, but it is possible to conceive of such individual differences in structure and attachment of tendons as to make them only approximately correct for some.

If we assume that they are generally valid, then we have in experiments with the flexors of the last phalanges, and with the abductors of the first and fourth fingers, nearly ideal general conditions for ergographic work, namely, practically complete isolation of the action of a single muscle, angular movements of the phalanx directly proportional to the shortening of the muscle, and a possibility of calculating the extent of movement and the actual force exerted by the muscle, approximately

without, and very closely with, the aid of x-ray photographs. If the force of contraction of the flexor of the last phalanx is known, we may calculate the strength of the flexor of the second from the force exerted by the two combined, and we may then proceed to ascertain the effect of both in the flexion of the first.

IV.

While the reference of the records to elementary geometrical properties and relations is the only foundation for obtaining absolute and generally comparable results, we can, for certain purposes, refer them to another standard, namely, to the variations in the height of the lift with a given load. The changes produced by fatigue may thus, for example, be compared with those due to increasing the load.

To ascertain approximately what the change in the height of lift is in response to a series of equal additions to, or subtractions from, the load is easy; but the records are somewhat variable. Successive lifts may shorten or lengthen not simply in a regular but in a more or less irregular and periodic fashion, through temporary changes in the muscle, or in the nervous elements. If the variations in the load are made in an arithmetical series, the subject benefits by the suggestion of regularity; if the presentation is irregular, he is often surprised and makes abnormal records. The usual procedure has been to make both a regular and an irregular series of changes. In the records here reproduced only the regular series are given. While these records are variable they are not so much so but that some fairly general features may be discovered.

How nearly the series of lifts or the corresponding fatigue curves would be the same under the different conditions that may exist, I am unable to tell precisely. Nearly all the experiments at my disposal (about 700 single series), were made with four young men between twenty and thirty, under what appeared to be normal conditions; a few records were obtained from five or six others. The majority of the records agree with the illustrations given, but there are some exceptions. For example, one subject, who gave a nearly straight, though slightly convex-concave, fatigue curve in the winter, five or six months later gave a curve decidedly convex with an abrupt

ending. The maximum pull, the load and the rhythm were the same.

In any case the results must be compared with the unchanging geometrical standards discussed above, to enable us to say in what way the series of lifts or the fatigue curves vary in comparison with the shortening of the muscle, and so to state definitely what is taking place.

With regard to the series of lifts for the different phalanges, the outline of a series corresponding to regular gradations in the load is nearly a straight line in the case of the abductors and the flexors of the last phalanges, when the total change in the load is from the maximum to half the maximum, or the reverse. With the flexors or abductors, a convex is a more frequent deviation than a concave outline; with the extensors, the reverse is true.

In the fatigue curves at the right of each series of lifts (see the figures below), the load was one-half of the maximum; and the interval between lifts, two seconds. The fact that the fatigue curves were not taken at the same time as the series of lifts, except in the case of Figure 10, will explain the difference between the maximum pull in the lifts and fatigue curves in Figures 7, 8, 9. It will be seen that the outlines of the series of lifts and the fatigue curves correspond fairly well. I do not believe this relation is invariable, but just what differences occur or under what conditions they take place, I am unable to say.

Figure 7 has been given partly because the results are typical for the flexor profundus of any finger, within the limits indicated above and as far as the point X; and partly because of the striking recovery of power by the subject when he had nearly reached the point where he would be unable to move the load. Lombard's results were unknown to him and the recovery came as a surprise. Such pronounced recoveries of power have usually not occurred in the work of those who have assisted me. I have, however, several similar records from this one subject and small variations have been observed in all. In one other case, these recoveries became very marked for a short time, though they had not occurred at all in occasional experimenting for some years previous. Why they should be prominent in some and not in others, or why they should appear

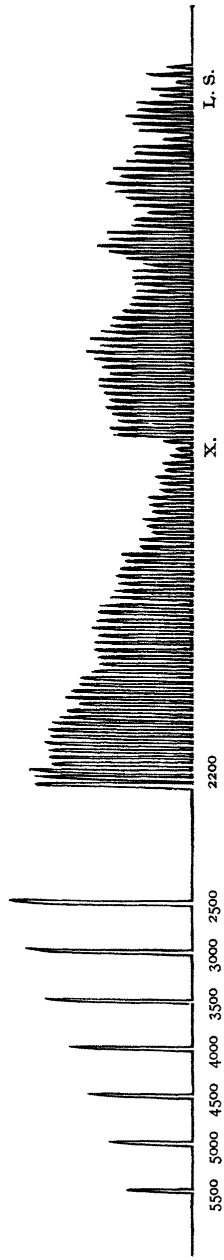



FIGURE 7. *Flexor profundus, first finger of right hand.*

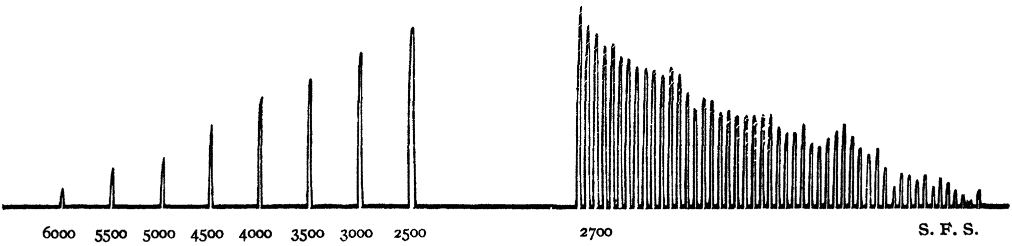



FIGURE 8. *Abductor indices, left hand.*

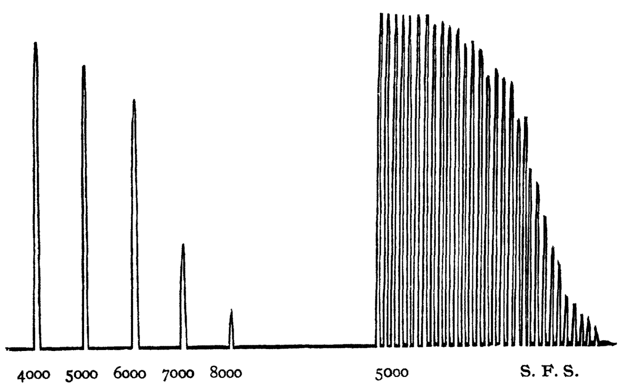



FIGURE 9. *Flexor sublimis aud flexor profundus combined. First finger left hand.*

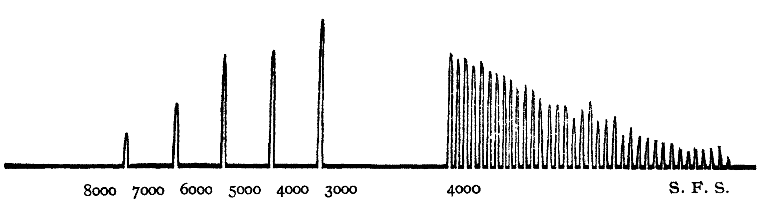



FIGURE 10. *Chiefly the flexor sublimis. First finger left hand.*

at one time and not at another in the same person under apparently similar experimental conditions, seems at present obscure.

Figure 8 gives a result from the abductor indicis of the left hand. Records from the abductors and from the flexors of the last phalanges have usually resembled one another. Figure 9 gives results differing from the rest. In this experiment the rotation occurs at the second joint, and a long thimble has been pushed tightly over the last two phalanges; we therefore have here the combined effects of the flexor profundus and the flexor sublimis.

Figure 10 gives the curve obtained from the same finger under similar conditions except that a short thimble has been pushed over onto the second phalanx leaving the third phalanx free to move. With this arrangement the series of lifts and the fatigue curve resemble those obtained from the third phalanges. It is probable that we have to do in this case chiefly with the flexor sublimis. As will be seen from the above records, the force of contraction decreases gradually with the flexion of a phalanx till it is only about a half of the maximum at the limit of motion. For the flexor profundus to be effective in bending the second phalanx, when the third phalanx is free, the latter must first be bent to its full extent and the muscle must be shortened still further. The force it can bring to bear will evidently be small.

In general, under the conditions mentioned, a fatigue curve from a single flexor or abductor is likely to be a long uniform curve approximately rectilinear, often slightly convex-concave, sometimes convex and abrupt, and occasionally a little concave; fatigue curves from the extensors are usually long and slightly concave. Experiments with the extensors may be made either with the last or the last two phalanges.

## V.

Figure 11 illustrates the mode of fixation of the hand to secure the isolation of the abductor indicis of either hand. All the parts are completely adjustable so that experiments may be made with children as well as with adults; this is true also of the arrangements for the flexors and extensors. This experi-

ment presents two difficulties—one already mentioned, that of the position of the thumb, the other the finding of the center of rotation. If the finger be bent slightly and a dot be made at the center of the first joint, in a line bisecting the angle of the metacarpus and the first phalanx, this will not be far from the center of rotation when the finger is straightened. On the palmar side the middle transverse line serves as a guide, and one is aided also by observing there more easily the center of rest of the skin as this phalanx is abducted or adducted. By aid of calipers the evidence from both sides of the hand may be compared. When the center has been determined the hand is so adjusted that this center is made to coincide with the centering point of the center gauge Ga, which is then removed.

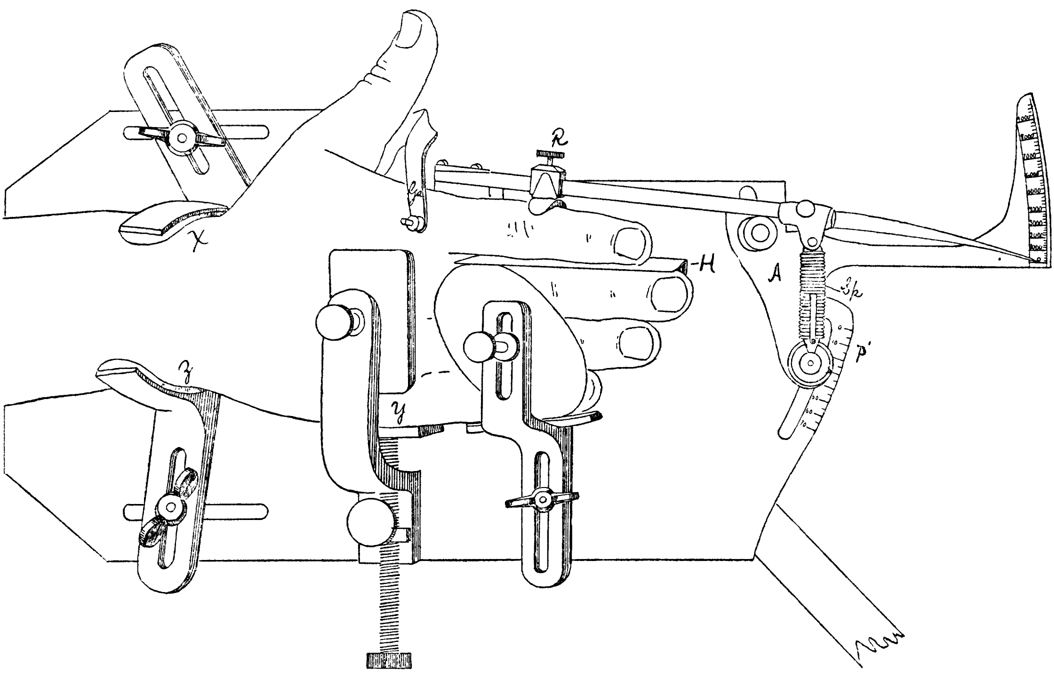



FIGURE II.

It will be seen that the downward pressure exerted when the abductor indicis contracts is met by the platform at Y. The upward pull on the metacarpals of the first finger and thumb is resisted by the clamp X, while its upward pull on the first phalanx may give rise to whatever movement it can. These and the rest of the clamps keep all parts of the hand in a fixed position and prevent them from contributing to the movement of the first finger.

For experiments with the abductor of the little finger, the same system of clamps is used, but the instrument is inverted and the movement of the finger is made downwards. The point of application of the load is immaterial unless the finger bends under the strain, or pain is felt. The place usually selected is that directly over the second joint. The angular adjustment of the saddle R takes place by movements of A. This moves in two concentric slots, the center being the center of rotation of the lever. Therefore, whatever adjustment may be made, the pointer will always remain at the zero of the scale whenever the end spring is used. All the abductors are well exposed for electrical stimulation, especially so the abductors of the little fingers. The angle at which the phalanx begins to work is as important in these cases as in those previously considered, but I believe nothing more is necessary than to hold the hand straight forward and make all parts tight after centering, though a record may be kept of the angles used. For many experimental purposes the abductor indicis is very convenient; it is of medium strength, not liable to strain by ordinary work, and does not readily become painful.

## VI.

The most important and most difficult part of ergographic experimentation has now been discussed. The second deals with the character of the load or resistance, and with modes of registration. The dynamometers and dynamographs, which preceded the ergograph, were spring instruments. Fick's tension indicator for experiments with the abductor indicis had a strong spring as a resistance, and was designed, as the name indicates, to register the tension of the muscle with a minimum of shortening on its part, that is, to leave the muscle practically

of the same length, or isometric throughout a contraction. Of more recent dynamometers, Kellogg's registers the pressure by the rise of a column of mercury in a tube of small diameter.

In the original ergograph, Mosso made use of weights instead of springs, partly perhaps because weights were customary in myographs for excised muscles, and he believed a similar reference to elementary properties of length and weight would be possible with the ergograph, and partly because it enabled him a little more readily to estimate the total amount of external work.

Criticism of the Mosso ergograph during the past ten years has not only pointed out the absence of the necessary isolation of the muscles employed, but has also been partly directed against the exclusive use of weights as a resistance. The inertia of the weights, the friction of the working parts, the failure of the apparatus as a whole to keep the contractions isotonic, the absence of definite means for selecting the load desired, the fact that the fatigue curve will end abruptly when the muscle can no longer lift a given load, and the lack of general convenience are among the criticisms that have been offered. It has also been asserted that the record of the external work executed does not represent even with approximate correctness the total amount of physiological work done. In raising a weight, moving it equal distances at different stages in the contraction, is not equally expensive; work also is done in sustaining or lowering as well as in lifting the weight. As a result several experimenters have preferred spring resistances, with which some of the above disadvantages, such as inertia and the abrupt ending of the fatigue curve, may be avoided; and a number of important observations and experiments have been added to the list.[1]

Yet with a removal of the errors noted above, isotonic contractions have a special interest. They permit a comparison with a great deal of experimentation on excised muscles and they make a convenient standard if heights of contractions are

[1] Cattell: Science, N. S., V, 1897, p. 909; Vol. IX, 1899, p. 251.

Binet and Vaschide: Examen critique de l'ergograph de Mosso, L'Année Psychologique, Vol. IV, 1897.

Robert Müller: *op. cit.*

to be studied. The series of variations in height and tension, with a series of increasing or decreasing loads, together with the corresponding fatigue curves taken under many different conditions, certainly represent definitely measurable changes which it does not seem probable experimenters will soon neglect. In the use of springs, the isometric procedure of Fick represents uniform conditions, permitting the making of comparable records, which will doubtless prove to be of much value both for such purposes as those for which it was employed by Fick,[1] Schenk,[2] and Franz,[3] and for the measurement of the maximum tension of a muscle in connection with other forms of experiment, particularly the isotonic.

Since the maximum force of contraction varies with the initial degree of flexion, it will be best to take as the standard measure the force exerted when the muscle is extended so that the phalanx makes an angle of 180° with the preceding part of the finger. To obtain this measurement something like the isometric method will be most convenient.

With springs of different degrees of extensibility the work that may be done or the tension that may be produced by a contraction will not be the same—the greatest tension being registered by the spring permitting the least, and the greatest amount of work by that permitting a medium, shortening of the muscle.[4] While this renders results obtained by muscles of different strength with such springs difficult of comparison, nevertheless the use of them offers opportunities for several interesting experiments like those from which these conclusions were drawn, so that we may demand that an ergograph to be of general use must furnish means for these as well as for the more important isometric and isotonic experiments.

An especially important requirement is this, that it shall be possible to use all these different forms of resistance under exactly the same conditions, that is, with the same adjustment

[1] Fick: *op. cit.*

[2] Schenk: Ueber den Verlauf der Muskelermüdung bei willkürlicher Erregung und isometrischem Contractionsact. *Pflüger's Archiv*, Vol. LXXXII, 1900.

[3] Franz: On the Methods of Estimating the Force of Voluntary Muscular Contractions and on Fatigue. *Am. J. of Physiology*, 1900.

[4] Franz: *op. cit.*

of the phalanx and its muscle in order that comparisons of records may be made with certainty.

Figure 12 shows the manner in which it is sought to attain these ends in the instrument here described.

For isotonic contractions we have the strong spring M S in the tube; it is variable in length and tension by a screw at the lower end and is supplied with a scale. The increment of tension occurring when the lever is moved is compensated for by the spring C S, which is therefore called the compensating spring. An account of a spring myograph is given by Dr. Grützner[1] in which compensation for the increment of a spring is obtained by adjusting it for each tension to a given angle with the lever to which the muscle is attached.

It will be seen that for the first half of the possible movement of the lever R, C S re-enforces the pull of M S with a gradually decreasing power till a zero point is reached near the middle after which it counteracts M S with a gradually increasing force. The compensation is of course not quite perfect but sufficiently so; the difference within the usual range of movement cannot be readily detected with a spring balance stretching 20 cm. per kg. and applied 10 cm. from the center of rotation.

It holds, whatever may be the tension of M S, and may be easily adapted to main springs of different strength; it also applies to the combined increments of M S and the coiled spring by which the pen is moved back.

For isometric contractions we have the spring Sp, the mode of attachment of which can better be seen in Figures 6 and 11. As was indicated above, it may be used not only for isometric experiments but also in obtaining the maximum force of contraction for the estimation of the resistance to be used in isotonic experiments. Experiments with springs of different degrees of extensibility may be made by using a dividing band or by putting other springs in the place of Sp.

The scales for M S and Sp, the main divisions of which are in hektograms, correspond in their units and are constructed with the lever in motion so as to include the effects of friction

[1] Dr. P. Grützner: Ein neues Myographion. *Pflüger's Archiv*, Vol. XLI, 1887.

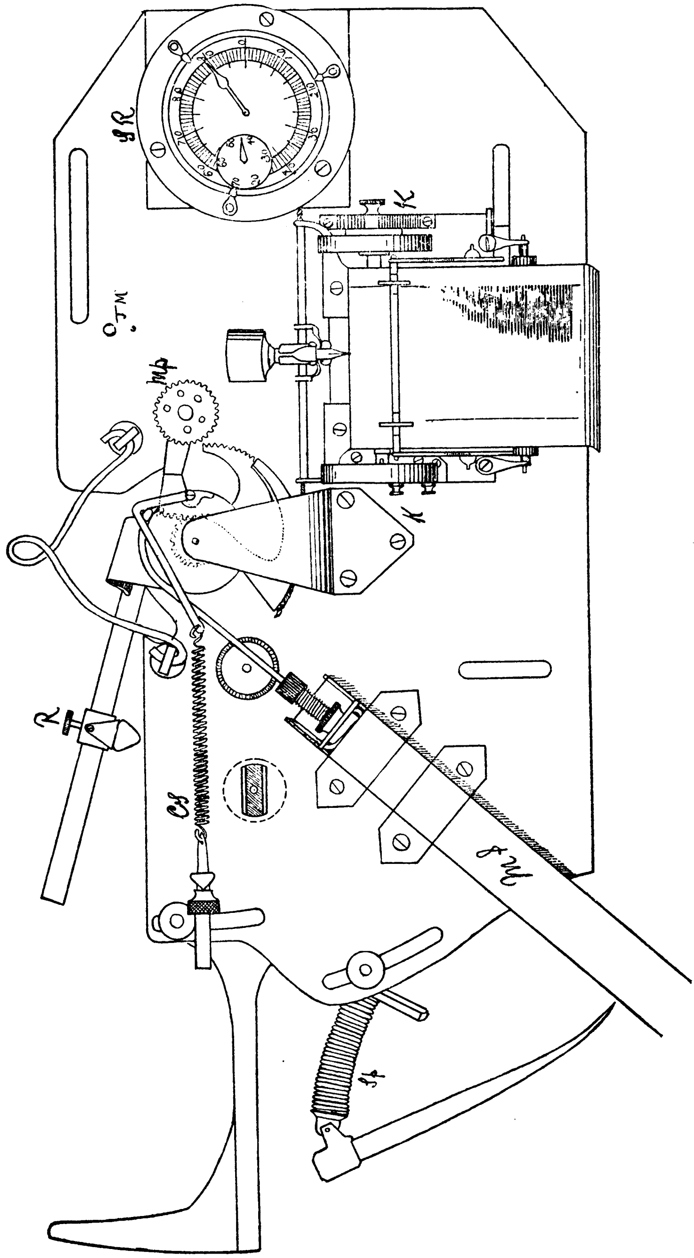


FIGURE 12.

and the resistance of other parts of the apparatus. The force of the springs is referred in the calculation of the scales to a radius of 31.83 mm. or a circumference of 200. It is by a sector of a wheel of this circumference that the graphic records are made on K K so that the amount of external work done is obtained in Hg mm. by multiplying the scale reading of M S or Sp, in the first case by the length, in the second, by half the length, of the up strokes taken singly.

The regulating mechanism of the little kymograph K K is made of the train of wheels and a cylinder escapement of a cheap stop watch; the rim of the balance wheel has been cut away so that what remains of the wheel vibrates very rapidly. It has been in use a great deal during the past five years but does not appear to be badly worn yet. A small fountain pen makes the record on a continuous roll of paper.

For isometric contractions, the length of the graphic record is multiplied ten times by pushing the wheel M P into gear. In this case, the spring that pulls the pen back to the right has such a mechanical advantage that the contractions start with a small initial load. Should it at any time be desirable to avoid this initial load, the pen must be disconnected and dependence placed upon a record secured by air transmission to an ordinary registering tambour and kymograph, from a receiving tambour placed at T M. This method has, however, a still more important use in that it makes it possible to study the character of single contraction curves at the same time that the fatigue curve is traced on K K.

In the first form of the instrument this mode of registration was used exclusively but it was liable to a great deal of inaccuracy and indefiniteness. The use of celluloid tambour tops, resembling the tops of aneroid barometers, such as are made by Sandström at Lund, would doubtless prevent the trouble due to deterioration of the rubber, which is the chief source of error.

S R is a device like Fick's Arbeitssammler and gives the sum in mm. of all the up strokes in fatigue curves, by the isotonic method. In this kind of experiment it is only necessary to multiply the readings of S M by those of S R to have at once the external work in Hg mm. In the isometric experiments the strokes must be measured singly.

The interval between contractions, and the rate of movement with which each contraction is executed, must be made as nearly definite and uniform as possible. To do this simply with the aid of a metronome requires great care. Even if the stroke is begun at the proper time, the rate of movement and the amount of rest taken between strokes may vary greatly. Just how great a difference in fatigue curves can be produced by such variations I am unable to state. I believe quite a difference may be made.

Several rather definite plans may be adopted ; the contractions may, for example, be made with the utmost rapidity, or they may be made with an effort to make the upstroke in the first half of the interval and the down stroke in the second half. This, also, is a definite procedure ; but a great deal of energy is spent in relaxing slowly. Between these two methods lie a number of less definite ones, among them what seems with a two-second interval like the most natural of all. The lever is lifted somewhat rapidly, a special effort is made near the top so that more time is expended there, particularly in raising, but also to a less extent in lowering the load, which is then allowed to descend rapidly but not so as to strike hard on the arrest; there the lever is allowed to remain for about a quarter of a second, when the next contraction begins. With care this rhythm may be made fairly definite, but the same duration of contractions and relaxations must be maintained whatever may be the height of the stroke.

In the apparatus at the Carolinska Institute, already mentioned, this problem is solved by having two endless bands with cross bars running, one up, the other down, while the subject of the experiment must move a similar band running in the center so as to equal the speed of the band moving up in the contraction and the speed of the one moving down in the relaxation.

No special devices of this kind have been used in the present case, but considerable assistance in the teaching of the different rhythms has been obtained by moving the finger in the rhythm desired directly before the subject, while the time is kept by aid of a metronome. This makes a vivid impression and is easily followed. If not the best, it would certainly be a good

method to adopt in experimenting with the various factors of rhythm.

The plan of Kraepelin of relieving the finger in the return movement from all pressure, by having a mechanism to catch and hold the weight at the heights reached by successive lifts, makes the record of external work approach more nearly to what the muscle actually accomplishes and prevents the liability to change in the rate of lowering the weights, but it does not necessarily make the rate of raising the weight any more nearly regular. This may still be slow or quick or variable at different stages so that in the comparison of records the results thus obtained may not be any more accurately proportional to the facts than the others. In the apparatus at the Carolinska Institute a similar purpose is accomplished by having the weights raised or lowered, as may be desired, by electrical power.

The peculiar arrangements of the ergograph described in this paper would not prevent the application of such a device, nor does it seem to me that the mechanical work involved is especially difficult. It could be accomplished by mounting a quarter circle of a strong gear wheel on the axis to operate against two or three wheels so proportioned as to give considerable speed to the last. By applying an adjustable friction to this, and by having a ratchet in the system so that the upward movement would be free, it would, I believe, be fairly easy to relieve the phalanx of pressure on the return.

Whatever device may be employed, the important thing is to make the movements as nearly uniform in character as possible in the different lifts, both in the same and in different experiments, unless the matter of rhythm is itself the subject of study.

A number of other attachments, such as one to do the work of the Mosso ponometer, would not be difficult. This might be substituted for *A*, Figures 6 and 11.

## VII.

For the purpose of a brief survey, ergographic experiments may be classified under three heads. Under the first we may place those made for the purpose of ascertaining the relation of

the shortening of the muscle to the force it can exert, or to the fatigue curve it will give under different conditions, and those for determining the seat of the fatigue or of periodic changes of power.

One of the most striking results in this field, obtained in the last few years, is the discovery that with a certain interval and the proper reduction in the load, a certain load is found that may be lifted to about the same height for a considerable period. A somewhat similar experiment may be made with springs as the resistance (in this case the heights of the strokes representing the pressures) will fall till a certain level is reached, which may then be maintained for a considerable time. If the interval between the first contraction and the beginning of the level phase had been found to be fairly constant in the same persons under apparently similar conditions, it might not have proved to be a more significant fact, but it would probably have been a more important individual measurement; this, however, does not seem to be the case.

Another series of experiments must also be mentioned under this heading.[1] From results obtained by alternate electrical and voluntary stimulation of muscles, in which it appeared that, when the muscle was fatigued for voluntary stimulation, it could be made to act by electrical stimulation, and then again by voluntary effort, some of the early experimenters advanced the theory that the fatigue and recoveries in the ergographic experiment were due to the fatigue and rest of the nerve cells. This theory led naturally to the view that the Lombard periodic curves were produced by central changes.

Treves reports that corresponding records may be obtained from the stimulation simply of the muscle itself, the periodic curves being due to an automatic lengthening or shortening of the muscle. Moreover, he argues that in alternating voluntary and electrical stimulation, the electrical stimulation may be regarded as submaximal and also as different in kind from the voluntary, both conditions permitting such recuperation as is

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[1]Dr. Zach. Treves: Ueber den gegenwärtigen Stand unserer Kenntniss, die Ergographie betreffend. *Pflüger's Archiv*, Vol. LXXXVIII, 1902.

Schenk: *op. cit.* T. J. Franz: *op. cit.*

found to take place. We have thus a thoroughgoing reference of a number of changes, which have heretofore been thought to be of central origin, to peripheral sources.

This does not, however, show that changes in force, even rhythmic changes, may not also occur in the nerve centers stimulating the muscle; from the close correspondence between muscle and nerve tissue in many elementary properties we might in fact expect this to be true. A certain class of psychic factors certainly affect the records; competition and encouragement often greatly augment both momentary strength and endurance, and discouragement or a sense of failure may produce the contrary effect. By pretending to present a subject with a series of increasing loads, successive reductions in the record may sometimes be observed, while as a matter of fact the load remains constant. Habits of effort, like habits of sleep, may no doubt exist or be established by training, and even variations like the Lombard curves are not impossible from such a source, but might be due to overcoming a reflex tendency to rest, just as we may by persistent effort counteract a tendency to fall asleep. Some variations in the ergogram are therefore clearly traceable to central and even mental factors, in others, these and peripheral factors may co-operate, and in still others peripheral factors may alone be responsible for the results.

In the second group of experiments we will place those in which the ergographic record is made a test of some general physiological condition. This field has been especially attractive, chiefly, perhaps, because of the direct practical inferences that may be drawn from the results. In this way the effort has been made to ascertain the effects of lack of food, loss of sleep, forced marches, mental fatigue, the effect of sugar, tea, coffee, alcohol, and tobacco, of diseases, and of some atmospheric conditions, like changes in the density of the air, also the effect of age, of time of day, and of various re-enforcing or depressing mental states.

Perhaps the most generally interesting and important recent question[1] in this field has been whether the ergograph may not

[1] T. L. Bolton: Ueber die Beziehungen zwischen Ermüdung, Raumsinn der Haut und Muskelleistung. Kraepelin, *Psychologische Arbeiten*, IV Band, 2 Heft. 1902.

be used as a means of studying the effects of fatigue, especially mental fatigue, in school children, as has been attempted by Keller, Kemsies, and others. That the ergographic record will not be as large as normal in conditions of great general exhaustion resulting from loss of food or sleep, from disease, or from excessive mental or physical labor, we may certainly take for granted even without the evidence offered by Mosso and Maggiora. Moreover, certain other aspects, such as regularity, ease of recovery, and the general outline of the curve, may prove to be as significant as the quantity of work in this matter. If a condition of general weakness were produced by work of any sort in the course of the day or week, and the general re-enforcement that accompanies effort had disappeared, we may feel confident that the fact would be revealed in the ergographic curves. But even in doing the same kind of work there is for a time an increase in the quantity done. Some observations would indicate corresponding variations with the amount of energy available from the start in the record of any test that may be applied, providing it does not require a change in interest or association. Thus, in the experiment with Dr. Adduco, Mosso found during the progress of exhausting mental work at first an increase, then a decrease, in the ergographic record. In experiments to determine the daily variations in rate of work, the highest records are usually not made early in the day, and the quantity of work in the addition tests applied by Laser[1] at the end of several successive hours of school work increased for the first three or four hours.

The ergographic record changes also with the emotional tone so that there are a number of stimulating and depressing factors that must be considered in using it as a test of exhaustion. Moreover the amount of change produceable in a test by fatigue is in proportion to its difficulty and the ergographic experiment is only moderately difficult.

The problem of the local and general character of fatigue must also be considered. While we can suppose that the poisonous condition of the blood in exhaustion, shown by Mosso to exist in the case of dogs, will be most detrimental in

[1]Hugo Laser: Ueber geistige Ermüdung beim Schulunterrichte. *Zeitsch f. Schulgesundheitspflege*, 1894.

the locality where the poison is produced, yet in the cases reported there were marked general effects. The reflex nervous effects tending to increase or inhibit work are probably also partly local and partly general. A third effect of work, namely, consumption of cell material, we may suppose to be more local in character.

Muscular fatigue at least is largely local; and the experiments of Weygandt, which show that under laboratory conditions there is no recuperation, as measured by the rate of work —in changing from one kind of mental occupation, such as adding or multiplying, to learning nonsense material by heart— unless the change was to something easier, do not seem to exclude the possibility of the specific local, as well as general character, of mental fatigue, inasmuch as the work to produce fatigue was continued for only a relatively short time. The conclusions may not apply to the exhaustion produced by continued application to a given subject till work with it becomes painful and we at least feel that it is necessary to take up something else for a time.

There may also have been such a balance in the stimulating and depressing nervous factors that the partly local character of the fatigue was masked for a while, and perhaps would be so in work of corresponding difficulty and duration in ordinary life. With these many factors to obscure the result and with fatigue partly a local phenomenon, we cannot expect to use the ergograph as a measure of exhaustion in the same way as we use a thermometer to measure temperature, but it may do a very important service in aiding us in its field of application to analyze the conditions and effects of work and fatigue, and in extreme cases, no doubt, if we need a test of exhaustion, to serve as one.

In the third class of experiments may be placed those in which the purpose is to aid in solving practical problems of work and training by making analogous tests with the ergograph. Such experiments would be those made upon the relation of the load to the maximum work,[1] the relative detriment of work at the beginning or near the point of exhaustion,

[1] Maggiora: Ueber die Gesetze der Ermüdung. *Du Bois-Reymond's Arch.* 1890.

the effects of various intervals between lifts, sustained and rhythmic work, cross training, the effects of warming up, and the conditions of recovery. This section of ergographic work will not be complete till a solution of all the elementary problems of neuro-muscular training and work has been attempted, and, as yet; only a few researches are at hand.

We must, of course, admit at the outset that experiments with small isolated muscles will not give results wholly and directly comparable with the training of different muscles or muscle groups. In some cases work may be so general and severe as to be limited more in character by circulation, respiration and digestion, than by the work of the muscles themselves. Yet the very fact of isolation from general disturbing factors, the possibility of definite variation and measurement, the relative ease of obtaining results, and the need of knowing in the analysis of neuro-muscular work what elementary factors are involved, are the very conditions which assure us of the permanent value of this kind of experimentation.